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CR-135815

Application of ERTS-1 imagery to detecting and mapping modern erosion features, and to monitoring erosional changes, in southern Arizona

SR 182

Roger B. Morrison
U. S. Geological Survey
Denver, Colorado

Maurice E. Cooley
U. S. Geological Survey
Tucson, Arizona 85717

1 August 1973

Type II Progress Report for period 1 February - 31 July 1973

Prepared for:

Goddard Space Flight Center
Greenbelt, Maryland 20771

E74-10074) APPLICATION OF ERTS-1 IMAGERY TO DETECTING AND MAPPING MODERN EROSION FEATURES, AND TO MONITORING EROSIONAL CHANGES, IN SOUTHERN ARIZONA (Geological Survey) 11 p HC $3.00 CSCL 08B G3/13

N74-11189

Unclas
00074

STANDARD TITLE PAGE FOR TECHNICAL REPORTS	1. Report No.	~~2. Govt. Accession No.~~	3. Recipient's Catalog No.
4. Title and Subtitle Application of ERTS-1 imagery to detecting and mapping modern erosion features, and to monitoring erosion changes, in southern Arizona			5. Report Date 1 August 1973 6. Performing Organization Code
7. Author(s) 1. Morrison, Roger B. (IN 050) 2. Cooley, Maurice E.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address U. S. Geological Survey Federal Center Denver, Colorado 80225			10. Project/Task Work Unit No. 182/36 11. Contract/Grant No. S-70243-AG-4
12. Sponsoring Agency Name and Address G. Richard Stonesifer Goddard Space Flight Center Greenbelt, Maryland 20771			13. Type of Report & Period Covered Type II Progress Rept. 1 Feb. - 31 July 1973 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstracts

In the completed first phase of study, ERTS-1 multispectral images have been used, without additional data, to prepare three maps at 1:1 million scale of the 18,000 sq. mi. project area: (1) modern (post-1890 A.D.) arroyos and channels, (2) types of stream channels and (3) potential erodibility (of soils, surficial deposits, and bedrock). Also completed is the collection and compilation of "ground truth" geologic, soil, and hydrologic data from published and some unpublished reports and maps. Partly completed and partly in progress is detailed mapping of 6 key study areas (parts of the project area) by interpretation of NASA's U-2 and RB-57 airphotos, supplemented with limited field study, to prepare 3 types of 1:125,000-scale maps: (1) modern (post-1890) erosion features, (2) potential erodibility, and (3) slope-relief. Also, these airphotos have been used to prepare 2 kinds of larger-scale strip maps of narrow zones along some segments of principal streams: (1) modern erosion features, and (2) Holocene geomorphology. These maps will be valuable for evaluating the maps made from the ERTS-1 and Skylab EREP data, and also to document the extent and seriousness of the modern erosion in large representative parts of southern Arizona. Field studies to obtain ground control for the photointerpretive mapping include (A) measurements, at many sites, of the depth, width, and channel characteristics of arroyos and gullies, and cross profiles of stream channels, flood plains, and Holocene terraces; and (B) stratigraphic measurements (and collection of archeologic data where possible) on the Holocene alluvial deposits. Significant conclusions from these extensive stratigraphic studies are: (1) slow deposition of sediment was the dominant process on stream lowlands throughout the project area for at least 2,000 years prior to 1890 A.D. (2) This deposition was broken by only two relatively brief and minor erosional episodes of regional importance, when channels no more than a third the depth of the modern channels were cut. (3) Thus, the modern erosion has produced within about 80 years substantially more and larger arroyos than any erosion episode during the last 2,000 years--and the end is not in sight.

17. Key Words and Document Analysis. (a). Descriptors

Quaternary geology and geomorphology, erosion monitoring, soil survey, flood assessment, environmental geology, modern geologic processes

18. Distribution Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 11
	20. Security Class. (This Page) UNCLASSIFIED	22. Price

FORM NDS-067(1-70)

(page 4 follows)

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Type II Progress Report

ERTS-1

a. Title: Application of ERTS-1 imagery to detecting and mapping modern erosion features, and to monitoring erosional changes, in southern Arizona. ERTS-A proposal no. SR 182.

b. GSFC ID No. of P.I.: IN 050

c. Problems encountered: None, except the delay in receiving 1:1 million-scale enlarged transparencies and 1:250,000-scale enlarged prints of ERTS-1 images (as explained in the 1 April Type I Progress Report).

d. Accomplishments during the reporting period:
Continued indexing and evaluating all the ERTS-1 70-mm images received for the project area (see p. 3 and Appendix A of the 1 April Type I Progress Report for discussion and samples of the evaluation forms).

Phase-1 results[1/]

Phase-1 mapping (interpretation of ERTS-1 images alone, without additional data) is completed. Three kinds of phase-1 maps have been prepared for the entire 18,000-square-mile project area, each at 1:1 million scale[2/]:

(A) Modern arroyo map: The Type II progress report for the period 15 July 1972 to 31 January 1973 included a map of the whole project area showing the modern arroyos detectable from ERTS-1 images. Images received subsequent to January 1973 do not justify significant additions to this phase-1 map.

We attempted to identify the areas of modern sheet erosion from the ERTS-1 images and concluded that such areas cannot be identified accurately at the phase-1 level of mapping.

(B) Potential erodibility map: This map, prepared during the present reporting period, shows four grades of potential erodibility of land-surface materials (soils, surficial deposits, and bedrock):

Map Unit	Description
1. Readily erodible materials. 1a. Of flood plains of the larger streams. 1b. Of bajada toe slopes.	Fine-textured unconsolidated alluvium (alluvial soils) of late Quaternary age, with little or no soil-profile development.

[1/] The appendix describes the seven-phase interpretation program followed in this project.

[2/] These maps are too big to be included with this report but preliminary copies are available to approved users.

Map Unit	Description
2. Moderately erodible materials.	Unconsolidated and slightly consolidated gravelly alluvium; also alluvium of various particle sizes with moderate soil-profile development.
3. Slightly erodible surficial materials.	Moderately consolidated alluvium; also poorly to moderately consolidated alluvium bearing soils with very strong calcium carbonate (caliche) accumulation.
4. Least-erodible materials.	Coarse bouldery alluvium and well-consolidated, resistant bedrock.

Essential to the objectives of this project is classifying and mapping the relative potential erodibility of the materials exposed at the land surface. Most important are the "readily erodible materials." These are predominantly alluvial soils of late Quaternary age that are unconsolidated or only slightly consolidated and fine textured (sand, silt, and clay). They occur chiefly in the interiors of the larger intermontane basins, beyond the zones of gravel deposition near the mountains. Here they are present not only on the flood plains and lower parts of the piedmont alluvial plains (bajada toe slopes) where the flood plains of the desert washes spread out and coalesce. Thus, the interior lowlands of the larger intermontane basins have extensive areas of readily erodible materials, commonly miles wide. (In places in the interior lowlands, however, older materials are present that resist erosion because of hardpan development--concentration of calcium carbonate, commonly called caliche--in the subsoil). Readily erodible materials also occur locally on stream flood plains in some mountain, hill, and gravel piedmont areas.

The most conspicuous areas of readily erodible materials are those of young alluvial silts and sands on the bajada toe slopes. Owing to their high reflectance and to the scantiness of their vegetative cover, these are much lighter toned than the gravel piedmont and bedrock areas. Some areas of these materials, especially the flood plains of the larger streams, appear dark-toned or varitoned because of natural and artificial vegetation--cropland, grassland, and riparian thickets of mesquite and other trees and shrubs, in various mixtures.

The following ERTS-1 frames were the principal ones used for the preparation of this and the other phase-1 maps: (Other frames were inspected briefly). 1068-17332 (29 Sep.), 1085-17330 (16 Oct.), 1085-17332 (16 Oct.), 1101-17215 (1 Nov.), 1101-17221 (1 Nov.), 1102-17274 (2 Nov.), 1102-17280 (2 Nov.). Band 5 was used mainly, band 7 to a limited extent; the other bands were used very little. (Viewing techniques are discussed at the end of this section).

(c) Types of stream channels: Classification and mapping of the main types of stream channels also are germane to the objectives of this project because the modern arroyo cutting is restricted to streams with certain types of channel characteristics. Mapping of types of stream channels at the phase-1 level has to be based on parameters that can be identified and are measured directly on the ERTS-1 images. These are (1) the widths of channels and flood plains, and (2) the size of the stream and its watershed (essentially, the stream order). Generally it is impossible at this level to identify details such as the depth and configuration of the channel and the configuration of the modern flood plain and older terraces.

The simplest classification of stream channels at this level is based on the width of the channel and flood plain:

1. Wide channels:
   1A. On a wide flood plain.
   1B. Without a flood plain.

2. Narrow channels:
   2A. On a wide flood plain.
   2B. On a narrow flood plain or without a flood plain.

3. Wide flood plains without recognizable channels:
   3A. In canyons.
   3B. In broad valleys or intermontane basins.

4. Streams without a definitely recognizable flood plain channel).

Such a simple classification has too many limitations to have much practical application. By including the size of watershed (or stream order) a more useful classification is developed:

1. Large streams (Gila and Salt Rivers):
   1A. Wide channel on wide flood plain.
   1B. Narrow channel on wide flood plain.
   1C. Channel not identifiable on narrow flood plain in canyons.

2. Main tributaries of streams of class 1 (Santa Cruz, San Pedro, and Verde Rivers and San Simon Creek):
   2A. Wide channel on wide flood plain.
   2B. Narrow channel on wide flood plain.
   2C. Channel not identifiable, flood plain easily distinguishable.
   2D. Channel distinguishable but not the flood plain.
   2E. Neither channel nor flood plain definitely distinguishable, as in canyons.

3. Tributaries of streams of class 2 and small tributaries of streams of class 1:
   3A. Both channel and flood plain identifiable.
   3B. Channel distinguishable but not the flood plain.
   3C. Flood plain distinguishable but not the channel.

4. (Not mapped). Some reaches of streams in class 3, tributaries of streams in class 3, and small streams tributary to classes 1 and 2: Neither the channel nor the flood plain is recognizable.

Modes of viewing the ERTS-1 multispectral images: Principal study was done with 70 mm positive transparencies of the ERTS-1 images, mostly with band 5 and at times with band 7. The images were viewed either under a binocular microscope (generally with 9X magnification, as described in the 1 February 1973 Type II Progress Report) or with an Old Delft scanning stereoscope (with 4.5 X magnification, simultaneously viewing two bands of the same frame, generally bands 5 and 7 or 5 and 6. Simultaneous viewing of two bands of the same frame seemed to enhance the contrast and to give more "depth" to the image, so that certain features and boundaries could be more readily distinguished. Positive transparencies at 1:1 million scale also were viewed under the Old Delft steroscope, either stereoscopically (for overlapping parts of adjacent frames) or two bands of the same frame simultaneously. For these larger transparencies, 1.5 X magnification gave better results than 4.5 X (the image became too fuzzy under the higher magnification). We found that such viewing of the black-and-white transparencies generally yielded more information and better detail than did viewing color-composites of the images, including those produced by additive color multispectral viewing with an I^2S Miniaddcol (register problems between different bands were reduced).

In all cases, regardless of the mode of viewing, data for the various phase-1 maps were plotted on transparent overlays to 1:1 million-scale positive transparencies of appropriate ERTS-1 images. Subsequently the data on the overlays were transferred to the base map.

Phase-2 and phase-6 results

In selected parts of the project area the modern erosion phenomena and features pertinent to the erosion problem are being mapped in detail, primarily by interpretation of ultrahigh (U-2 and RB-57) airphotos. This study (phase 2 of our program is to provide a basis for evaluating the mapping done from the ERTS images (both the normal images and those enhanced by special processing of the digital tapes by the Jet Propulsion Laboratory) and eventually from Skylab EREP data. The phase-2 mapping is being combined with phase-6 studies (limited field studies to obtain ground control), with an intimate feedback between the two, in order to attain maximum efficiency and accuracy in the fundamentally photointerpretive mapping. We evaluated various parts of the project area for potential sites for the detailed mapping, selected six key areas, (table 1) and established priorities for their mapping. The key study areas represent all the major environments pertinent to the erosion problem in terms of geology, soils, climate, topography, and vegetation.

We are preparing three kinds of maps at 1:125,000 scale for each of these study areas: (1) modern (post-1890) erosion features (arroyos, gullies, modern flood plains and terraces, and areas of sheet erosion and deposition, (2) potential erodibility (of soils, surficial materials, and bedrock), and (3) slope-relief. A fourth kind of map at this scale, of vegetative cover, may be prepared for some study areas if time permits. In addition, two kinds of "strip maps" at larger scales are being prepared for narrow zones along certain segments of the larger streams, such as the Santa Cruz and San Pedro Rivers: (1) modern erosion features, and (2) Holocene geomorphology (including stream terraces, flood plain, and channels of Holocene age). Both the larger- and smaller-scale maps will include field measurements of the depths, widths, and channel characteristics of arroyos and gullies, and cross-profile of stream channels, flood plains, and Holocene terraces, at many sites. Some of these sites have had similar measurements taken once or twice during the past 16 years by Cooley.

Table 1--Status of detailed airphoto-interpretive mapping of key study areas

Study area name	Tucson	Mesa	Sonoita	Benson-Sierra Vista	San Simon Creek	Railroad Wash
Approx. size (sq. mi.)	2,000	500	500	1,000	500	150
			1:125,000-scale mapping			
Slope-relief map	Done	----	Done	Done	In progress	----
Modern (post-1890) erosion features map	In progress	In progress	In progress	In progress	Done	----
Potential erodibility map	do.	do.	do.	do.	----	----
			Larger-scale strip mapping along principal streams			
Modern erosion features map	Done	----	----	In progress	In progress	----
Holocene geomorphology map	In progress	----	----	do.	do.	----

From the field (phase-6) studies in connection with this mapping, we have improved considerably our knowledge of the stratigraphy of the alluvial deposits laid down in the valley lowland during the last 2,000 years, and hence, our knowledge of the chronology of episodes of erosion and deposition during this time interval. (We also are evaluating the stratigraphic/chronologic record for the last 10,000 years--the entire Holocene--but evidence pertaining to older parts of the record is much more fragmentary than that for the last 2,000 years). We find that the alluvial deposits of Holocene age can be divided into several distinctive rock-stratigraphic units that commonly are separated by weakly developed soils and/or small erosional unconformities. Locally they contain archeologic and/or radiocarbon-datable materials. The post-1890 sediments can be clearly distinguished from earlier deposits. The various lithostratigraphic units of late Holocene age are being mapped widely over the project area and apparently they can be correlated in a time sense throughout this area. Thus these stratigraphic studies have yielded much-improved evidence on the erosional/depositional history in a large part of southern Arizona during the last several thousand years. (Our data are much more extensive than those previously available from studies of archeologic and other localized sites).

Significant conclusions drawn from these stratigraphic data are: (1) Slow deposition of sediment (aggradation) was the dominant process on stream lowlands for at least 2,000 years prior to 1890 A.D., everywhere in the project area. (2) The deposition was broken only by two relatively brief and minor erosional episodes of regional significance; each erosion episode lasted only a few decades to several centuries and the channels cut during them are rarely more than a third of the depth of the modern (post-1890) channels. (3) Consequently, there seems to be no doubt that the channeling (arroyo cutting and gullying) that has taken place since 1890 is much more serious than any during the preceding 2,000 years, throughout southern Arizona--and the end of the modern erosion episode is not in sight.

The environmental implications are obvious. Where deep arroyos are bordered by readily erodible materials, as commonly is the situation, the valley lowlands now are highly unstable--the modern erosion is rapidly removing the young alluvium, putting into jeopardy not only the best croplands and rangelands but also residential, industrial, and commercial development in the urbanized areas. (For example, the channel of the Santa Cruz River through the city of Tucson commonly is more than 30 feet below its pre-1890 flood plain).

Phase-3 results

We completed the collection and compilation of phase-3 data, including phase-3 potential erodibility maps insofar as practicable. Published geologic and soil maps are inadequate for preparing potential erodibility maps, except for small parts of the project area. However, the published maps, enhanced in places by data from Morrison and Cooley's previous studies, have permitted the preparation of both (1) a 1:1 million-scale map of the whole project area that distinguishes the least-erodible materials (bedrock) from the slightly to readily erodible materials and (2) similar, more detailed maps, compiled on 1:250,000 scale 1° x 2° quadrangles, for most of the project area. These "ground truth" maps will provide an additional basis for comparison with the photointerpretive maps made from ERTS-1 images and from U-2 and RB-57 airphotos.

Phase-4 results

Compilation of the phase-4 potential erodibility map of the entire project area at 1:500,000 scale is partly completed. This "enhanced information map" is produced by additional interpretation of ERTS-1 images in the light of supplementary data from the phase-2, 3, and 6 studies. Two additional phase-4 maps are already prepared at 1:1 million scale for the whole project area: (1) intensity of post-1890 arroyo cutting and channeling, and (2) types of stream channels (see discussion under phase-1 results). Correlations between these various phase-4 maps are very good. This suggests that ERTS-1 images will be useful for identifying the principal streams in other parts of the western United States (and possibly in other parts of the world) that have been severely affected by modern arroyo cutting.

Plans for next reporting period

(1) Complete the phase-2 and phase-6 detailed mapping of key study areas.

(2) Complete the phase-4 "enhanced information maps" of potential erodibility of the entire project area.

(3) Prepare phase-5 maps of selected parts of the project area, utilizing repetitive ERTS-1 images and airphotos to map any detectable erosion changes.

(4) Prepare the phase-7 map.

(5) Prepare a draft of the final (Type III) report.

e. Significant results and their practical application:

In the completed first phase of study, ERTS-1 multispectral images have been used, without additional data, to prepare three maps at 1:1 million scale of the 18,000 sq. mi. project area: (1) modern (post-1890) arroyos and channels, (2) types of stream channels, and (3) potential erodibility (of soils, surficial deposits, and bedrock). Also completed and compilation of "ground truth" geologic, soil, and hydrologic data from published and some unpublished reports and maps.

Partly completed and partly in progress is detailed mapping of 6 key study areas (parts of the project area) by interpretation of NASA's U-2 and RB-57 airphotos, supplemented with limited field study, to prepare 3 types of 1:125,000-scale maps: (1) modern (post-1890) erosion features, (2) potential erodibility, and (3) slope-relief. Also, these airphotos have been used to prepare 2 kinds of larger-scale strip maps of narrow zones along some segments of principal streams: (1) modern erosion in large, representative parts of southern Arizona.

Field studies to obtain ground control for the photointerpretive mapping include (A) measurements, at many sites, of the depth, width, and channel characteristics of arroyos and cross profiles of stream channels, flood plains, and Holocene terraces, and (B) stratigraphic measurements (and collection of archeologic data where possible) on the Holocene alluvial deposits. Significant conclusions from these extensive stratigraphic studies are (1) Slow deposition of sedimant was the dominant process on stream lowlands throughout the project area for at least 2,000 years prior to 1890 A.D. (2) The deposition was broken by only two relatively brief and minor erosion episodes of regional importance, when channels no more than a third the depth of the modern channels were cut. (3) Thus, the modern erosion has produced within about 80 years substantially more and larger arroyos than any erosion episode during the last 2,000 years--and the end is not in sight.

Category designation symbols: ID, 3G, H, I, 7F

f. Published articles:

(1) Morrison, R. B., and Cooley, M. E., 1973, Application of ERTS-1 multispectral imagery to monitoring the present episode of accelerated erosion in southern Arizona: NASA Sci. Tech. Info. Office, Symposium on significant results obtained from the Earth Resources Technology Satellite-1 (Goddard Space Flight Center, Mar 5-9, 1973), v. 1, Technical presentations, sec. A, p. 283-290.

(2) Morrison, R. B., and Cooley, M. E., 1973, Assessment of flood damage in Arizona by means of ERTS-1 imagery: Ibid, p. 755-760.

g. Recommendations: None

h. Changes in Standing Order Forms: None

i. ERTS Image Descriptor Forms: None

j. Data Request Forms submitted to GSFC, by data: None

APPENDIX

The seven-phase interpretation program

This project uses a seven-phase program of interpretation of ERTS-1 data.

Phase 1 consists of preliminary mapping of the post-1890 erosion phenomena and other data relevant to the erosion problem (such as the more erodible soils) using only the ERTS-1 imagery.

Phase 2 consists of photointerpretive mapping of the modern erosion phenomena and other features relevant to the erosion problem from U-2 and RB-57 ultrahigh aerial photographs, in selected parts of the whole study area.

Phase 3 involves compilation of available published and unpublished ground-truth data (hydrologic, geomorphic, geologic, soil, etc.) on maps of suitable scales, without using ERTS data.

Phase 4 is a comparison of phase 1, 2, and 3 products, with additional photointerpretation, to prepare "enhanced information maps," noting any differences and anomalies.

Phase 5 consists of additional analysis made from repetitive ERTS and ultrahigh airphoto coverage of the study area, noting any detectable erosional changes, such as widening, deepening, aggradation, or headward growth of gullies and arroyos, and also any added information (at least the differences in information content) on the features we are mapping resulting from time-variant phenomena such as changes in vegetation, soil moisture, and sun-elevation angle.

Phase 6 consists of appropriate field studies to obtain necessary supplemental ground-truth data, particularly to evaluate interesting features found in earlier phases.

Phase 7 is the delineation of any new information detected from the ERTS and ultrahigh airphoto data.